The CAPTAIN Program

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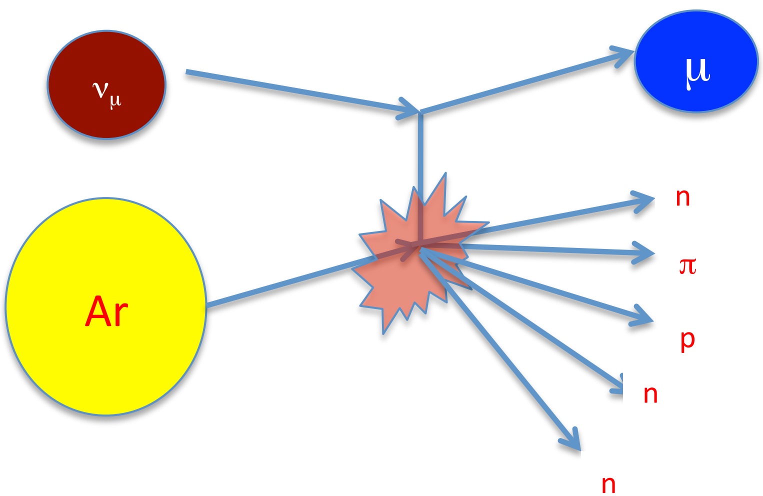
LANL
5 February 2015

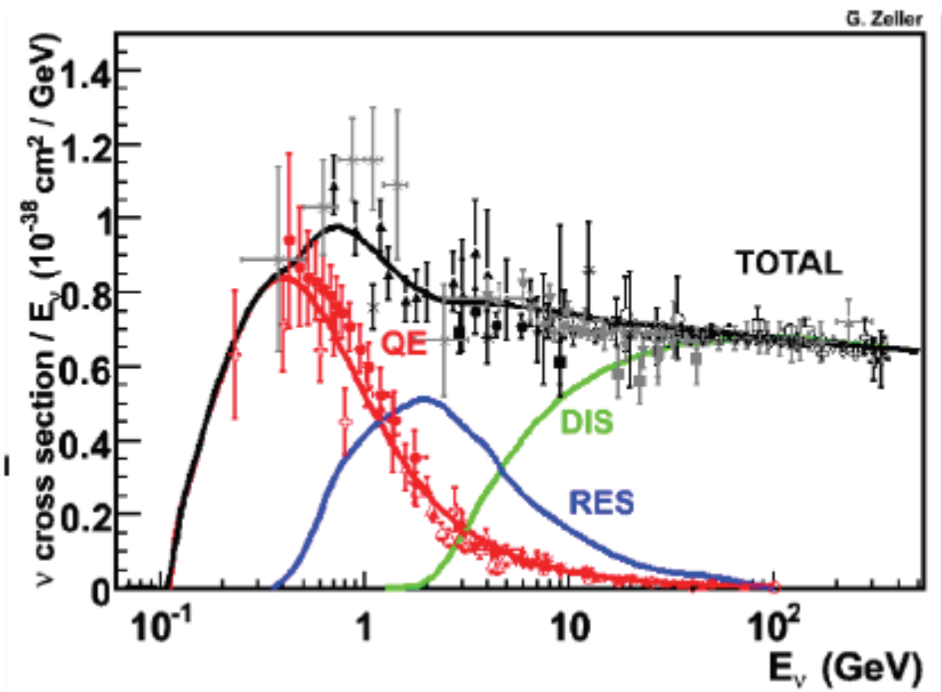
Outline

- ELBNF Physics Challenges
  - Medium-energy neutrino physics
    - accelerator neutrinos
    - atmospheric neutrinos
  - Low-energy neutrino physics
    - neutrinos from galactic core-collapse supernovae
- The CAPTAIN Program
- Current Status
- Summary

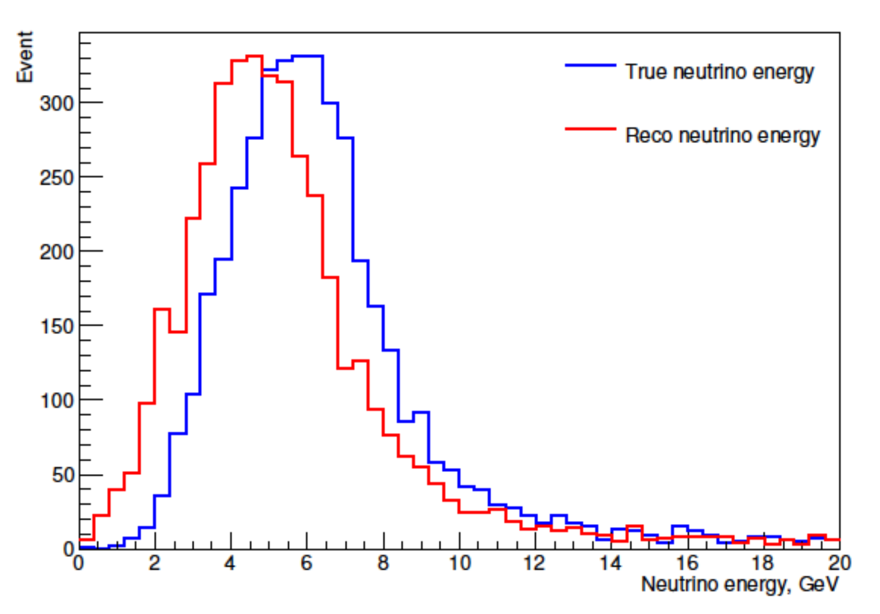
ELBNF Physics Challenges – medium-energy neutrinos

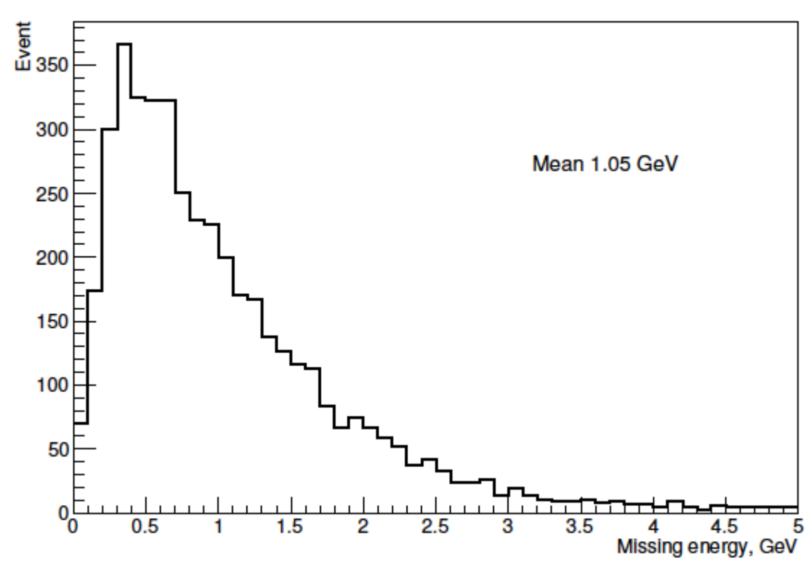
- ELBNF does long-baseline physics in resonance regime (1st Oscillation Maximum at ~2.4 GeV) and resonance/DIS cross-over regime
- Atmospheric neutrinos are measured in the same neutrino energy regime
- Neutrino oscillation phenomena depend on mixing angles, masses, etc. and neutrino energy
- Critical to understand the correlation between true and reconstructed neutrino energy

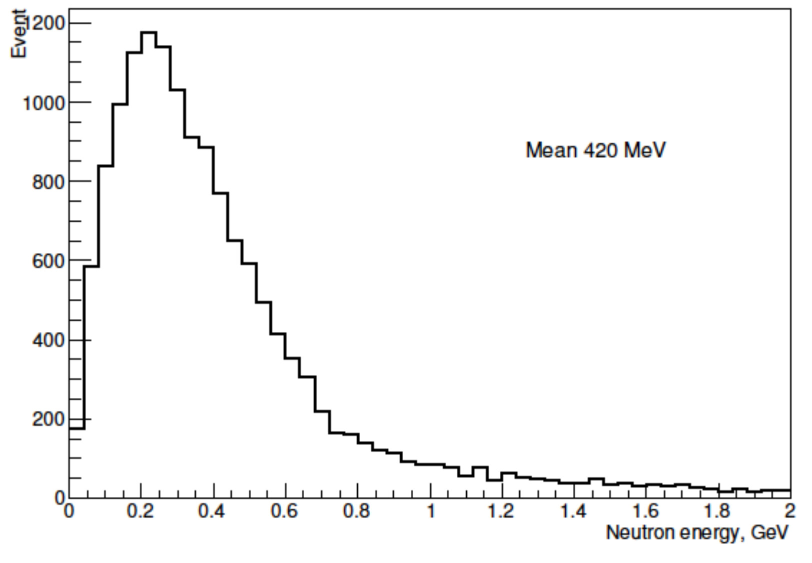




NuMI Medium Energy Tune



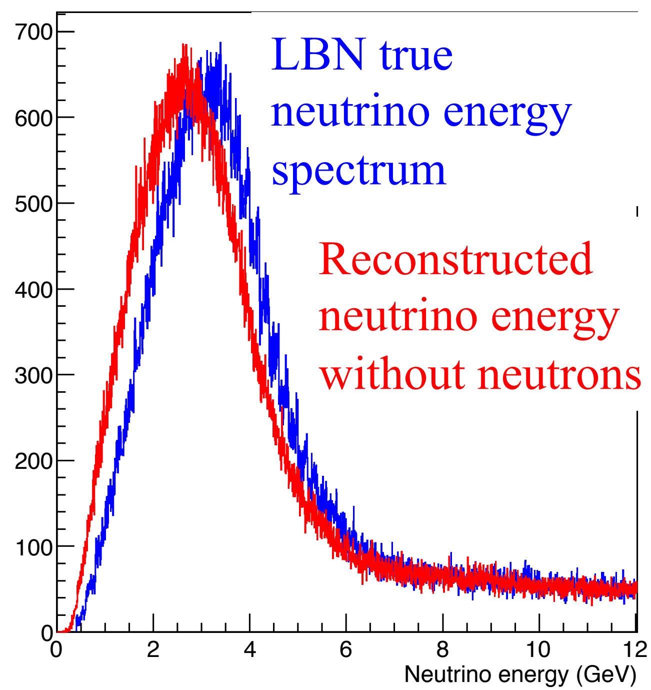




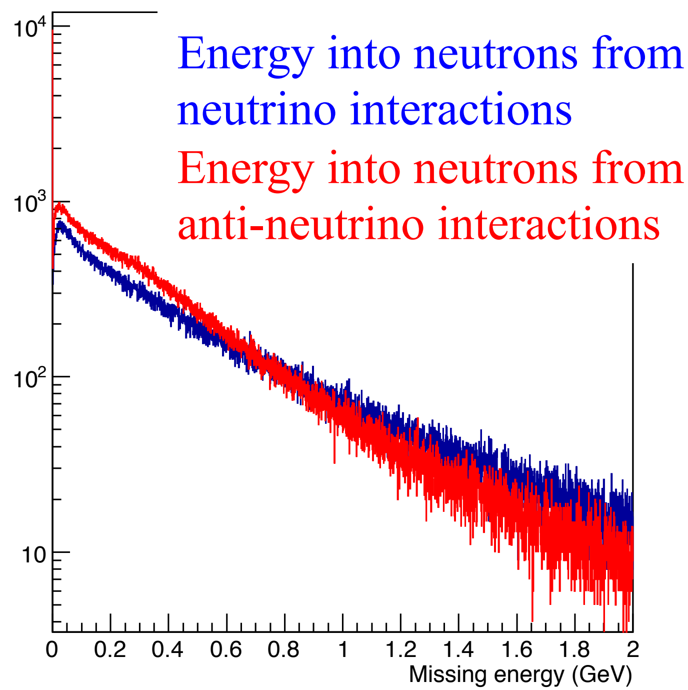
- Upper left: Blue is true neutrino energy; Red is reconstructed energy assuming no neutron reconstruction and perfect reconstruction of other particles
- Upper right: Total energy in neutrons. Note asymmetric distribution (and large uncertainties), so we cannot assume a constant ``offset'' to the neutrino energy reconstruction
- Lower right: Energy per neutrons
- All plots: NuMI medium energy tune, GENIE event generator ``out of the box''

LBNF Beam

LBNF Neutrino Energy Spectrum

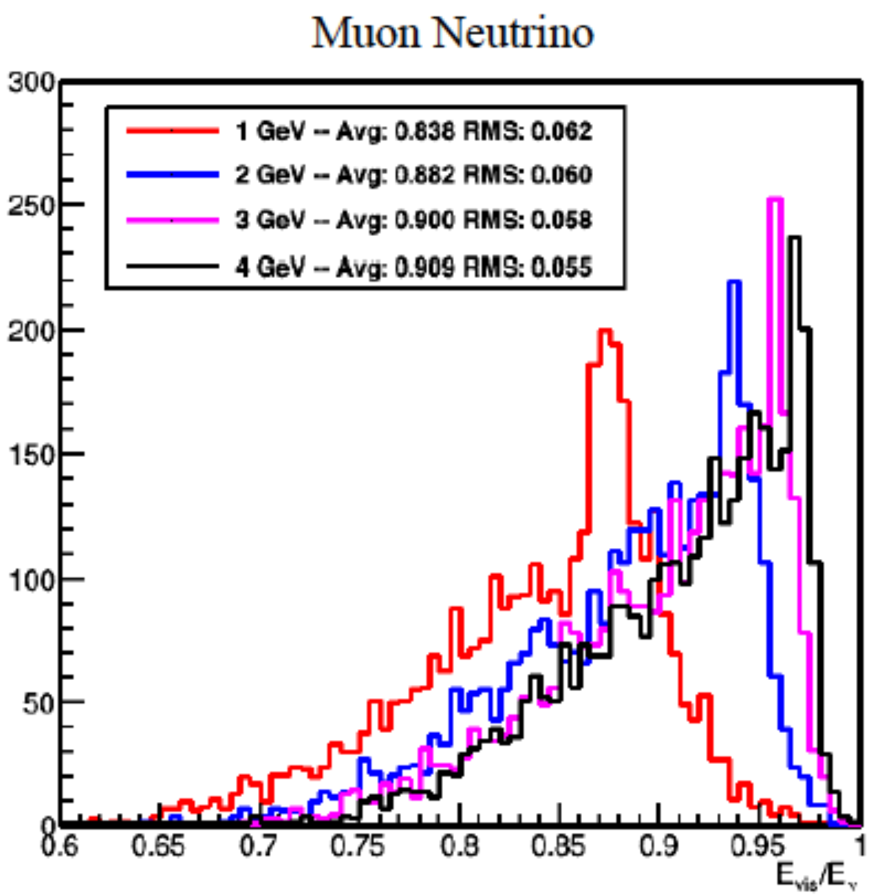


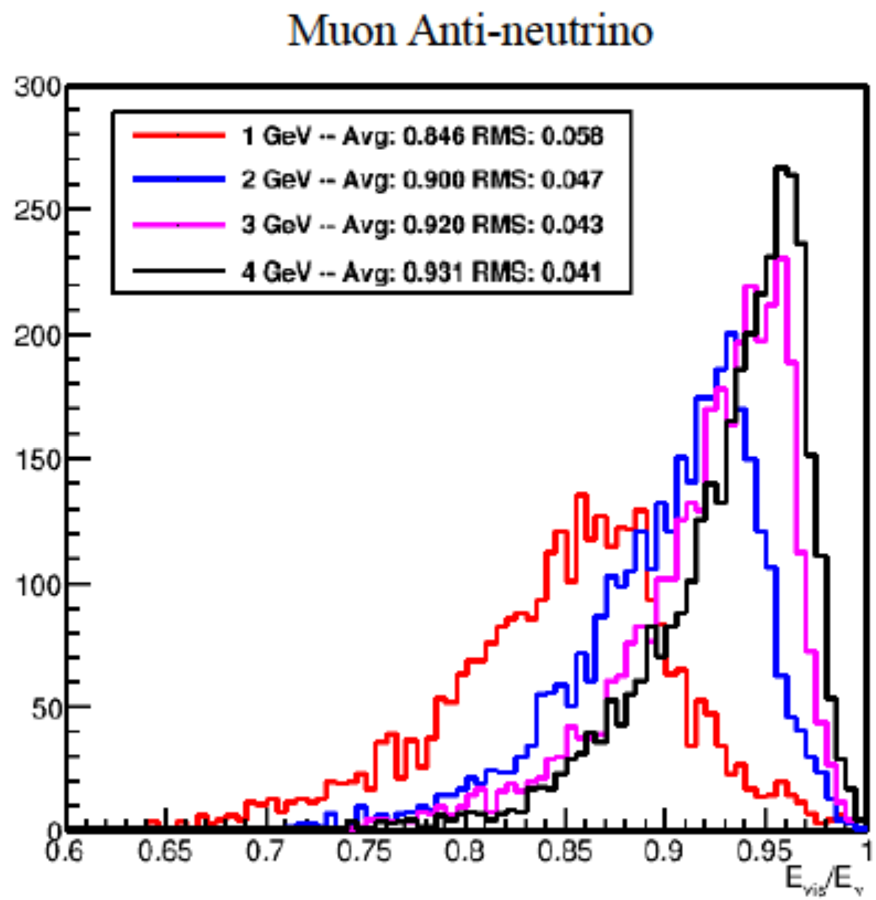
Outgoing energy in neutrons



- At LBNF neutrino energies, neutrons can carry away significant energy
- Uncertainties on the energy carried away are large and unconstrained
- The energy carried away differs between neutrinos and anti-neutrinos

Fraction of neutrino energy that is visible

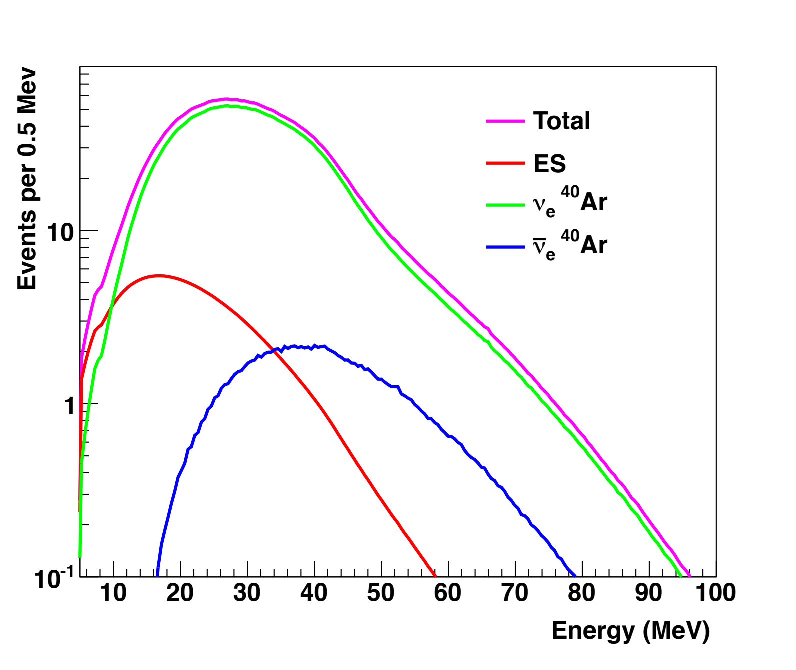




- Fraction is different for neutrinos and anti-neutrinos

- Clark McGrew at the Santa Fe LBNE Scientific Workshop (http://public.lanl.gov/friedland/LBNEApril2014/)

Supernova Neutrinos



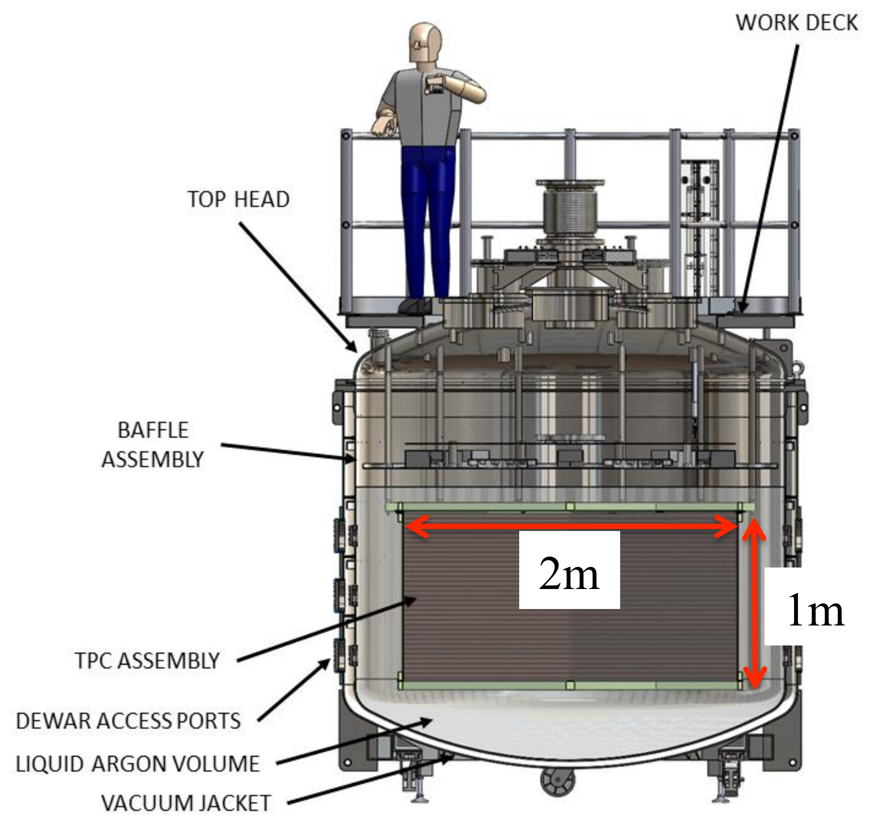
- Plot to the left and table below for 34 kilotons of liquid argon
- P5 report: ``The experiment (ELBNF) should have demonstrated capability to search for supernova bursts''
- Neutrinos in the supernova energy regime have never been detected with a liquid argon TPC
- Cross-section uncertain
- Detection efficiencies unknown

Channel	Events *Livermore* model	Events *GKVM* model
$\nu_e +^{40}\mathrm{Ar} \rightarrow e^- +^{40}\mathrm{K}^*$	2308	2848
$\overline{\nu}_e +^{40}\mathrm{Ar} \rightarrow e^+ +^{40}\mathrm{Cl}^*$	194	134
$\nu_x + e^- \rightarrow \nu_x + e^-$	296	178
Total	**2794**	**3160**

The CAPTAIN Detector

CAPTAIN: Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos

- CAPTAIN Detector
  - hexagonal TPC with 1m vertical drift, 1m apothem, 2000 channels, 3mm pitch, 5 instrumented tons
  - indium seal – can be opened and closed
  - photon detection system and laser calibration system
  - using same cold electronics and electronics chain as MicroBooNE (front end same as LBNE)
- CAPTAIN prototype
  - Hexagonal TPC with 30 cm drift, 50cm apothem, 1000 channels, 3mm pitch, 400 instrumented kg
- Physics program focused on challenges to ELBNF low-energy neutrino (supernova) and medium-energy neutrino (long-baseline and atmospheric) programs
  - Neutron running at LANL
  - Two LOIs to FNAL PAC
    - Run at BNB for low-energy neutrinos
    - Run at NuMI for medium-energy neutrinos – CAPTAIN Minerva



CAPTAIN Collaboration

- Alabama: Shak Fernandes, Ion Stancu
- ANL: Zelimir Djurcic
- LBL: Vic Gehman, Richard Kadel, Craig Tull
- BNL: Hucheng Chen, Veljko Radeka, Craig Thorn
- UC Davis: Hans Berns, Kyle Bilton, Daine Danielson, Steven Gardiner, Chris Grant, Emilja Pantic, Robert Svoboda, Nick Walsh
- UC Irvine: Craig Pitcher, Michael Smy
- UC Los Angeles: David Cline, Kevin Hickerson, Kevin Lee, Elwin Martin, Jasmin Shin, Artin Teymourian, Hanguo Wang, Lindley Winslow
- FNAL: Oleg Prokoviev, Jonghee Yoo
- Hawaii: Jelena Maricic, Marc Rosen, Yujing Sun
- Houston: Babu Bhandari, Aaron Higuera, Lisa Whitehead
- Indiana: Stuart Mufson
- LANL: Jeremy Danielson, Steven Elliott, Gerald Garvey, Elena Guardincerri, Todd Haines, Wesley Ketchum, David Lee, Qiuguang Liu, William Louis, Christopher Mauger, Geoff Mills, Jacqueline Mirabal-Martinez, Jason Medina, John Ramsey, Keith Rielage, Constantine Sinnis, Walter Sondheim, Ciara Sterbenz, Charles Taylor, Richard Van de Water, Kevin Yarritu
- Louisiana State University: Flor de Maria Blaszczyk, Thomas Kutter, William Metcalf, Martin Tzanov, Jieun Yoo
- Minnesota: Jianming Bian, Marvin Marshak
- New Mexico: Franco Giuliani, Michael Gold, Alexandre Mills
- South Dakota: Chao Zhang
- South Dakota State: Robert McTaggart
- Stony Brook: Clark McGrew, Chiaki Yanagisawa

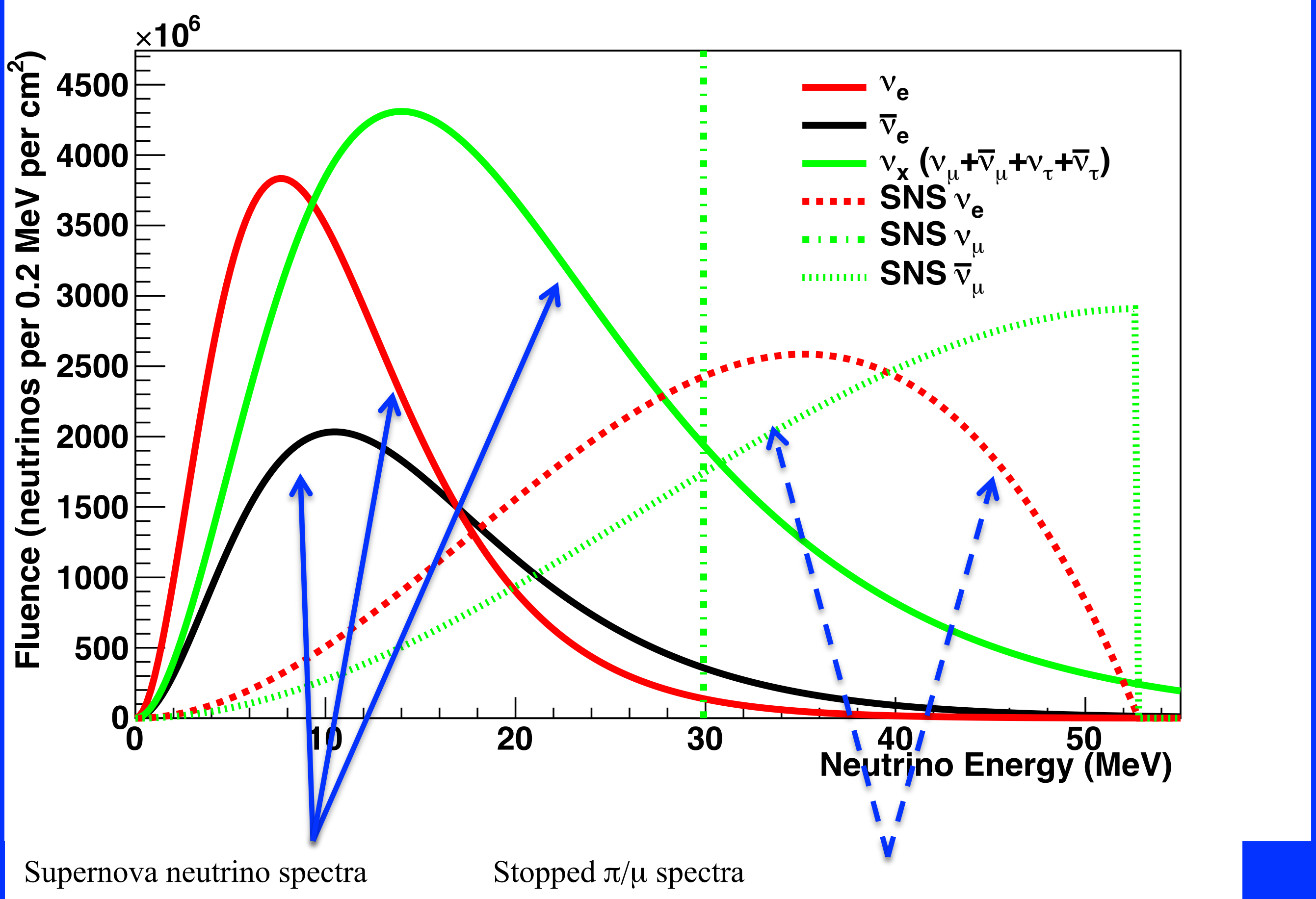
CAPTAIN Physics Program

Neutron Beam
Low-Energy Neutrino Beam
Medium-Energy Neutrino Beam

- Low-energy neutrino physics related
  - Measure neutron production of spallation products
  - Benchmark simulations of spallation production
  - Measure the neutrino CC and NC cross-sections on argon in the same energy regime as supernova neutrinos
  - Measure the correlation between true neutrino energy and visible energy for events of supernova-neutrino energies
- Medium-energy neutrino physics related
  - Measure neutron interactions and event signatures (e.g. pion production) to allow us to constrain number and energy of emitted neutrons in neutrino interactions
  - Measure higher-energy neutron-induced processes that could be backgrounds to ν_e appearance e.g. $^{40}Ar(n,\pi^0)^{40}Ar^{(*)}$
  - Measure inclusive and exclusive channels neutrino CC and NC cross-sections/ event rates in a neutrino beam of appropriate energy
  - Test methodologies of total neutrino energy reconstruction with neutron reconstruction

CAPTAIN-BNB

Running at a stopped pion source



From:arXiv:1211.5199

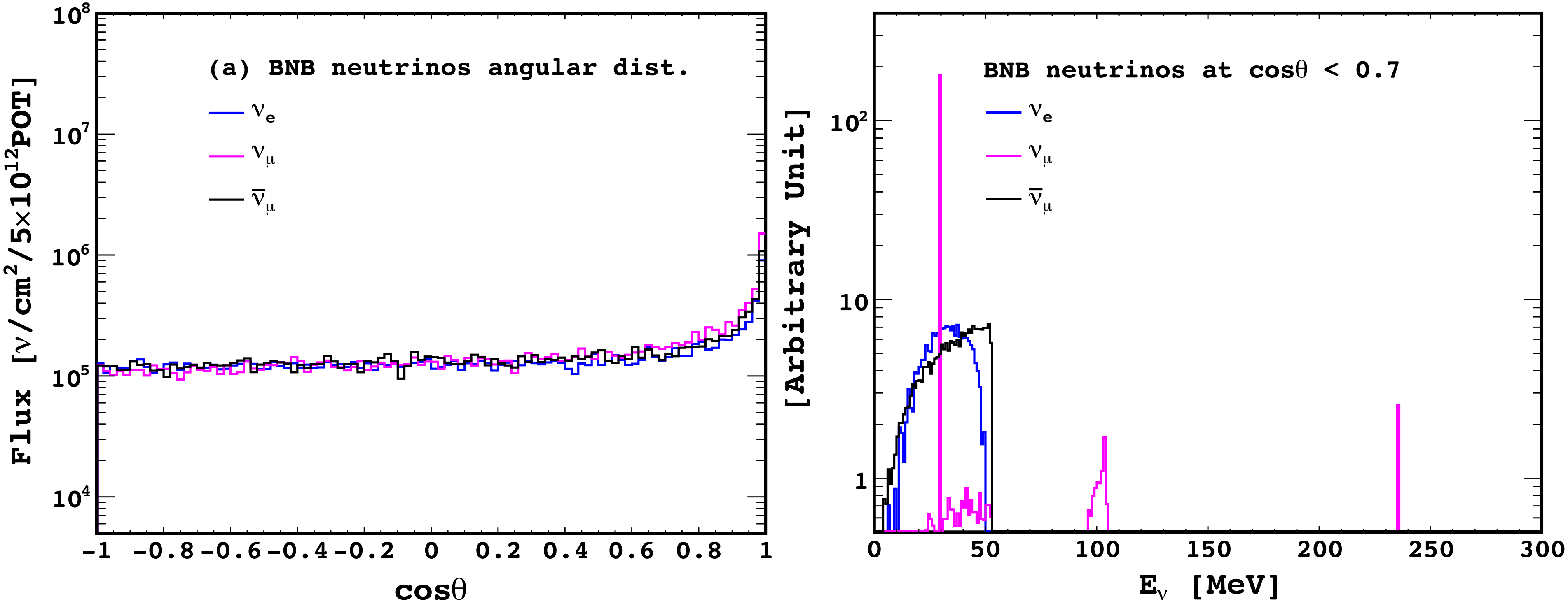
- Stopped pion source near ideal for cross-section measurement

CAPTAIN at the BNB

Fermilab:

- The only national laboratory in US dedicated to the particle physics
- Strong support on neutrino physics programs

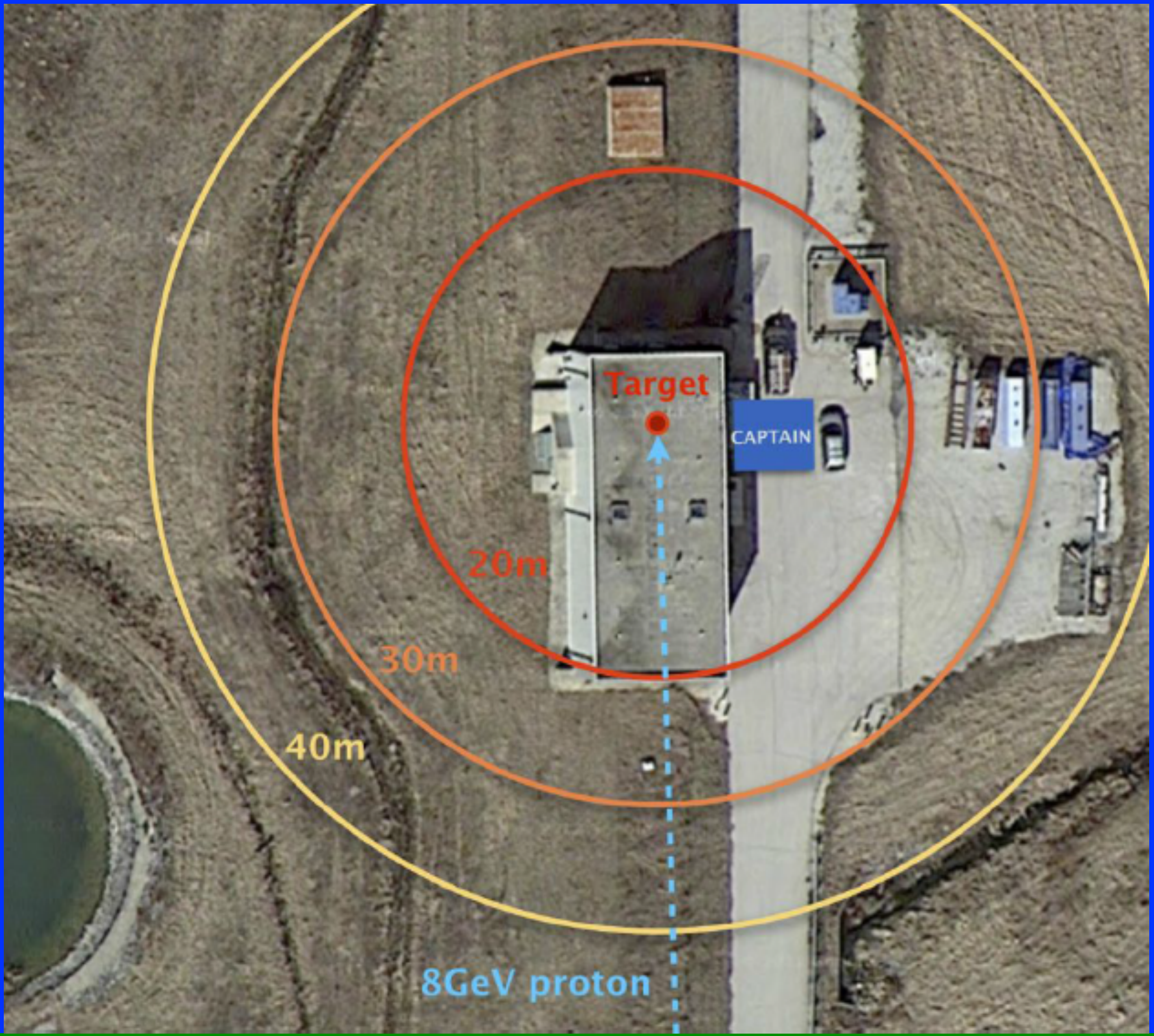
CAPTAIN at the BNB



- Left: Angular distribution of neutrinos at the BNB
- Right: Decay-at-rest neutrino spectra at the BNB (cosθ<0.7)

From: Phys.Rev. D89 (2014) 7, 072004

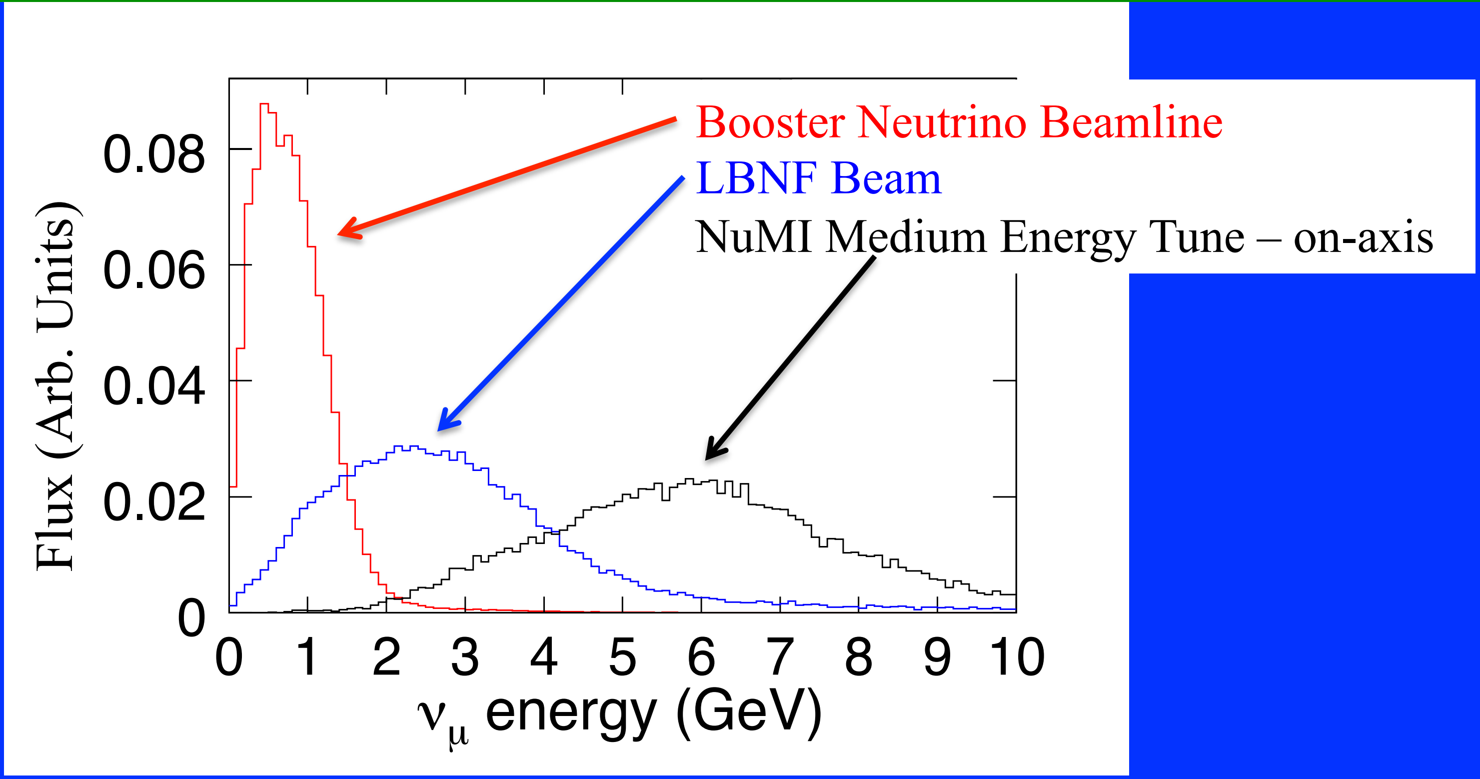
CAPTAIN at the BNB



- MI-12 hall with the target position noted
- Possible location of the CAPTAIN detector at ~ 90 degrees off-axis position
- Event rates of ~200 per year (2e20 pot)
- Neutron backgrounds must be mitigated
- If we run near the absorber with the beam in off-target mode (current MiniBooNE DM search), rates are potentially more than 3 times higher with lower neutron background

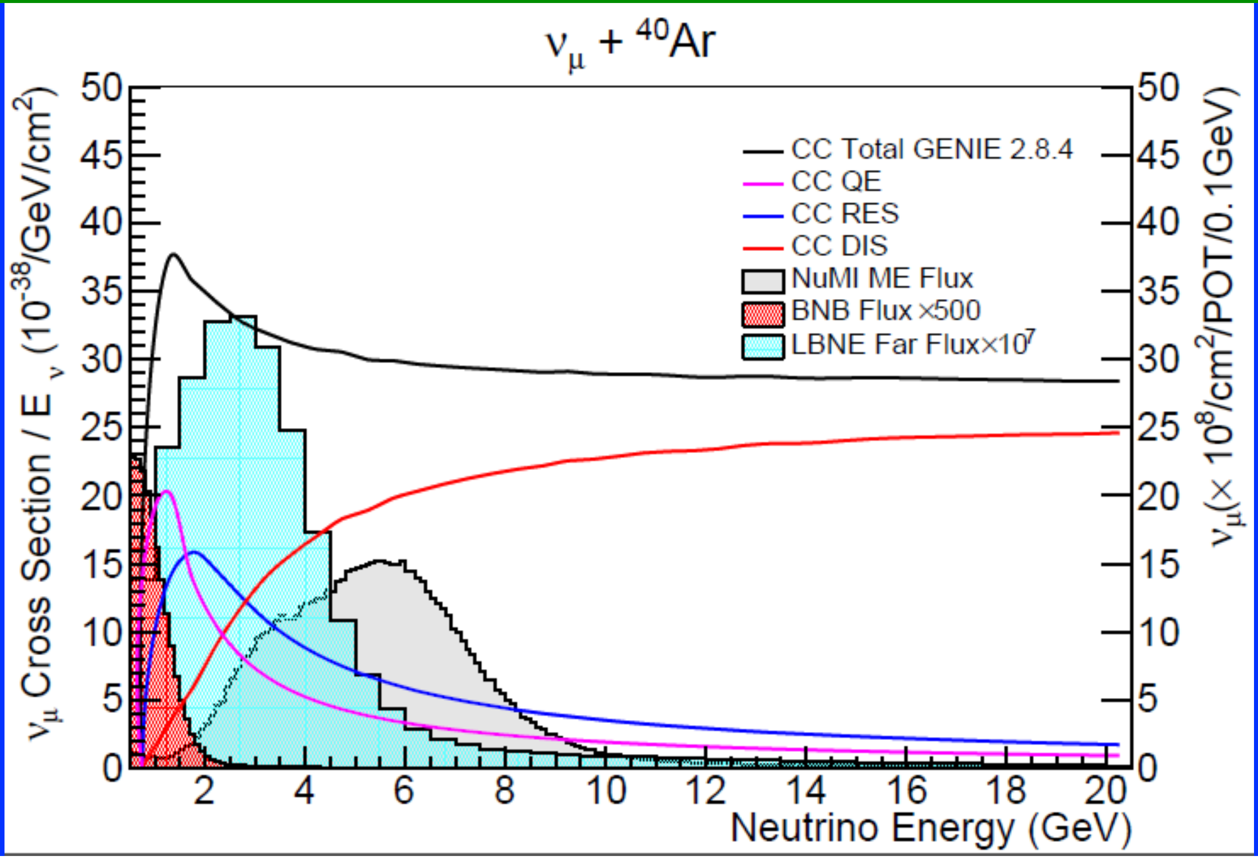
CAPTAIN-Minerνa

CAPTAIN at NuMI



- Fermilab NuMI beamline – will run in medium energy tune to support the Nova Experiment
- Complementary neutrino energy regime to MicroBooNE
- Important energy regime for ELBNF

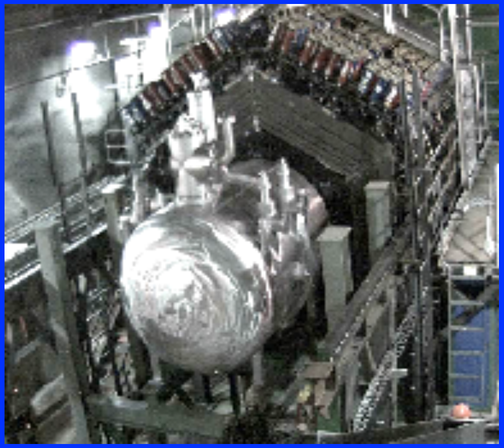
CAPTAIN at NuMI

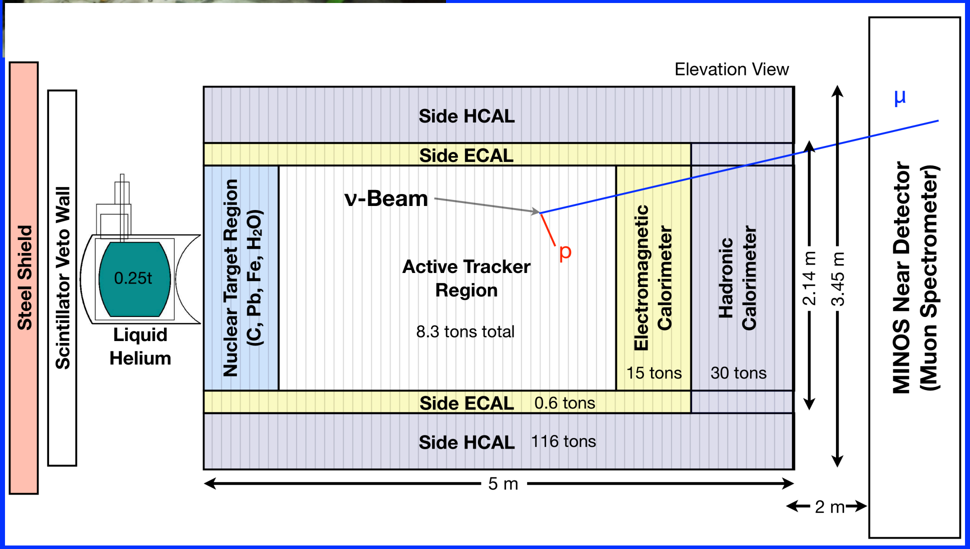


- Detailed exploration of threshold region for multi-pion and kaon production
- High-statistics data for algorithm development required for ELBNF
- Employment of methods for neutron energy reconstruction
- Early development of multi-interaction challenge

Minerva Detector

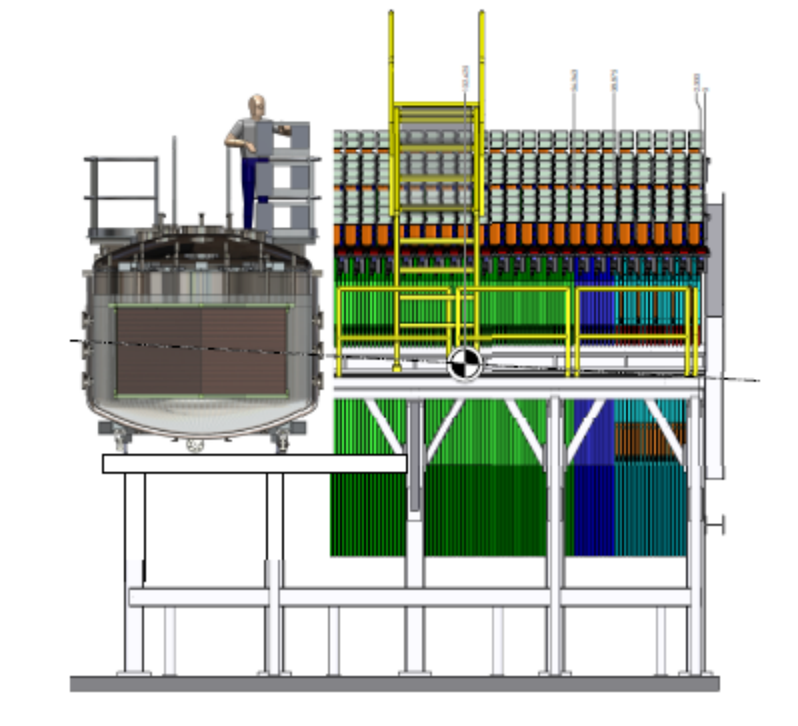
- Nuclear Targets
  - Allows side by side comparisons between different nuclei
  - Pure C, Fe, Pb, LHe, water
- Solid scintillator (CH) tracker
  - Tracking, particle ID, calorimetric energy measurements
  - Low visible energy thresholds
- Side and downstream electromagnetic and hadronic calorimetry
  - Good event energy containment
- MINOS Near Detector
  - Provides muon charge and momentum

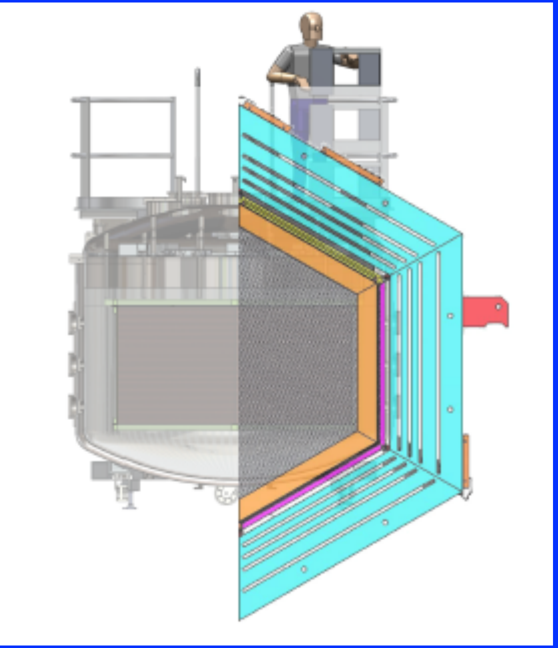




CAPTAIN Minerva

- Best way to deploy CAPTAIN at NuMI is to develop an integrated approach with Minerva

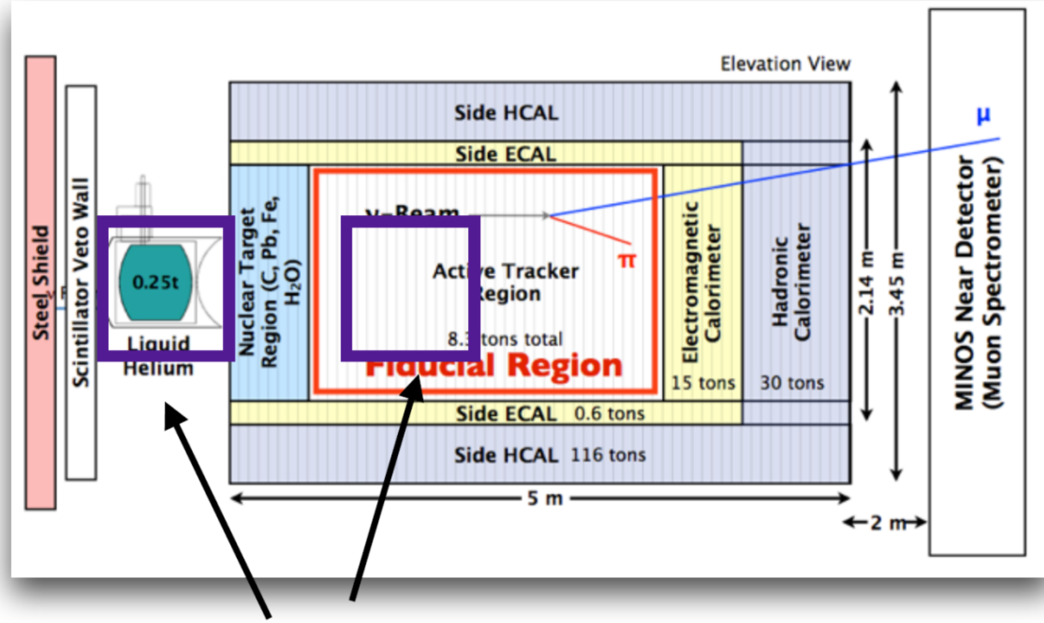




CAPTAIN Minerva

MINOS/MINERvA Hall

unscaled



Two possible locations:

1) Replace the He target with CAPTAIN
2) Remove the nuclear targets and part of the tracker (this would only be considered after MINERvA has accumulated 12e20 POT in antineutrino mode)

CAPTAIN Minerva

	Contained Events in CAPTAIN	Contained Events in CAPTAIN at pos 1 w/MINOS Match	Contained Events in CAPTAIN at pos 2 w/MINOS Match
CCQE-like	488,250	255,354	339,333
$CC1\pi^{\pm}$	191,250	59,478	88,930
$CC1\pi^{0}$	189,000	48,384	76,167

Table 1: Contained efficiency for CC events with a reconstructed muon using MINOS ND, assuming 6×10^{20} POT exposure.

- Overall containment efficiency 25%
- Detailed study of C/Ar cross-section comparison with active targets
- Anticipate data-sharing arrangement with ELBNF for algorithm development

CAPTAIN Status

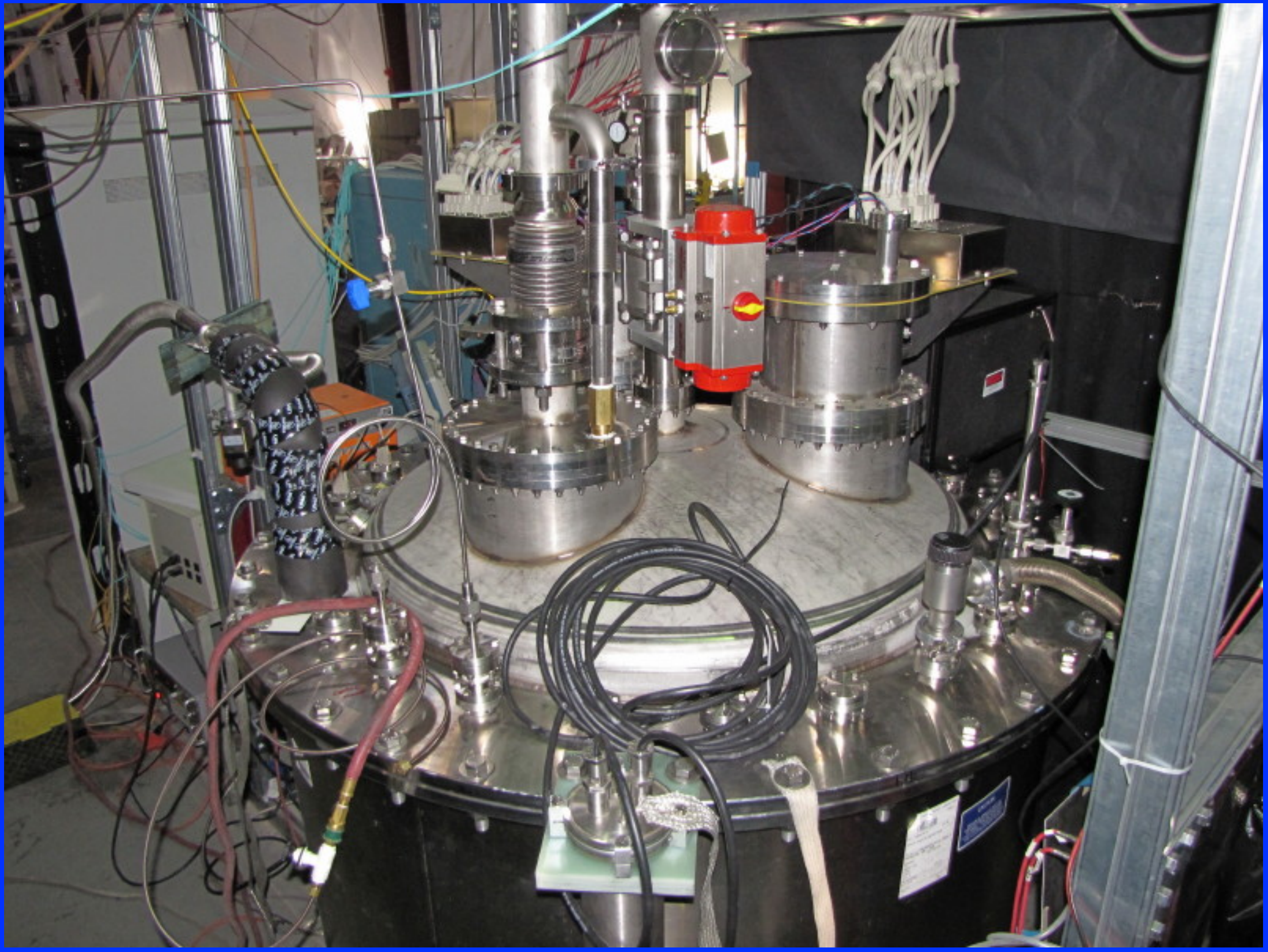
Prototype Detector

Postdoc Charles Taylor (LANL) prepares the prototype

Liquid nitrogen fill – summer 2014

- Tests of electronics and TPC, test of heatload

LAr engineering run – autumn 2014



View of cryostat and cryostat penetrations

- Filling procedure development
- Cryogenic and purification systems testing
- Data-taking, DAQ development
- Laser system testing

Mini-CAPTAIN and CAPTAIN

- Mini-CAPTAIN
  - LAr fill begins this month
  - Filling procedure improvements
  - DAQ improvements
  - Muon system integration
  - Recirculation system installed
- CAPTAIN
  - Cryostat, electronics, field cage in hand
  - Purification system at vendor
  - TPC wiring to be completed

Cryostat arrives at LANL (22 August 2014)

Summary

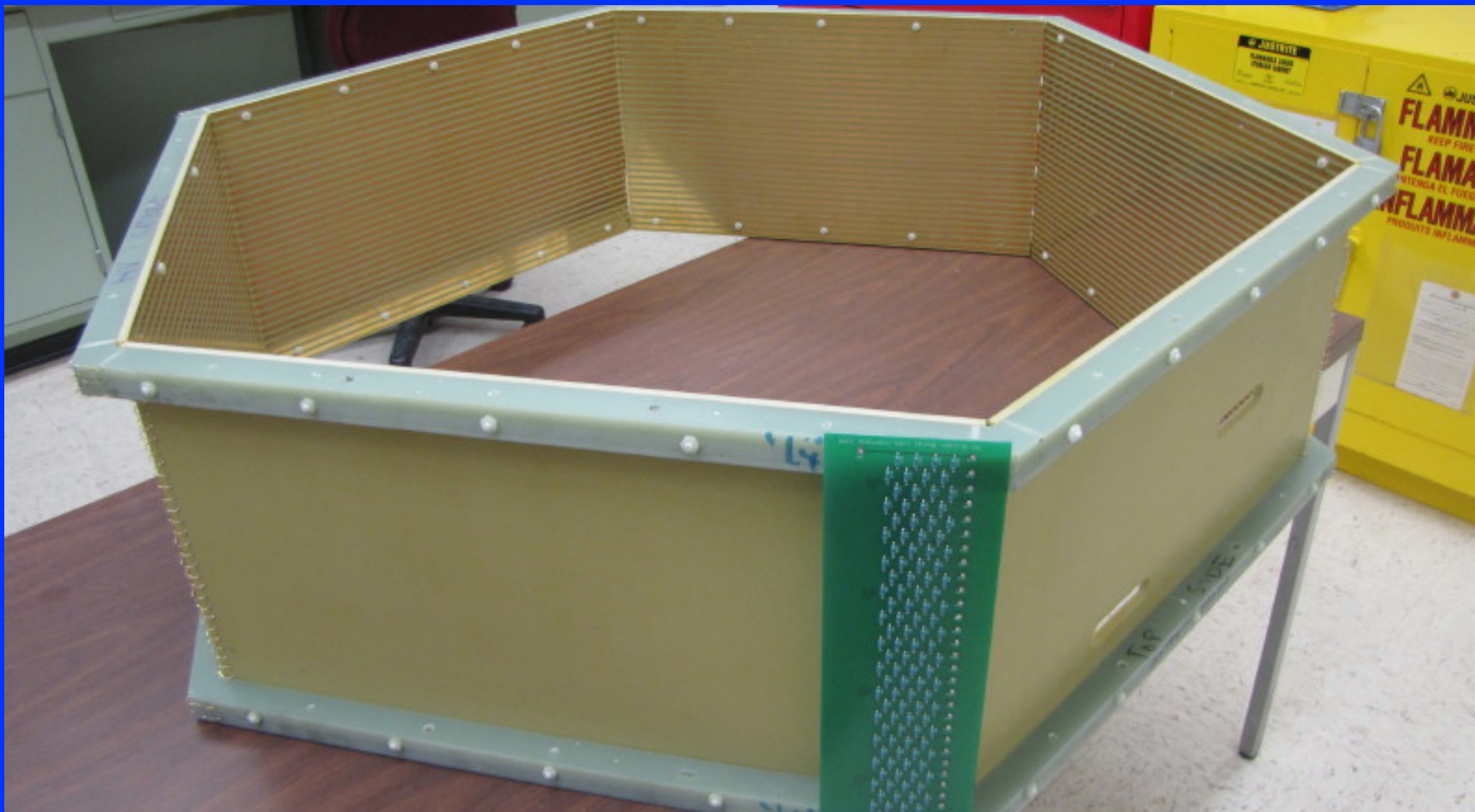
- ELBNF has several important scientific challenges
- CAPTAIN can address some of these with a run plan including:
  - neutron running
  - low-energy neutrino running CAPTAIN-BNB
  - medium-energy neutrino running – joint collaboration with Minerva as CAPTAIN Minerva
- Mini-CAPTAIN detector undergoing commissioning activities
- CAPTAIN detector ready for assembly and commissioning soon

Backups

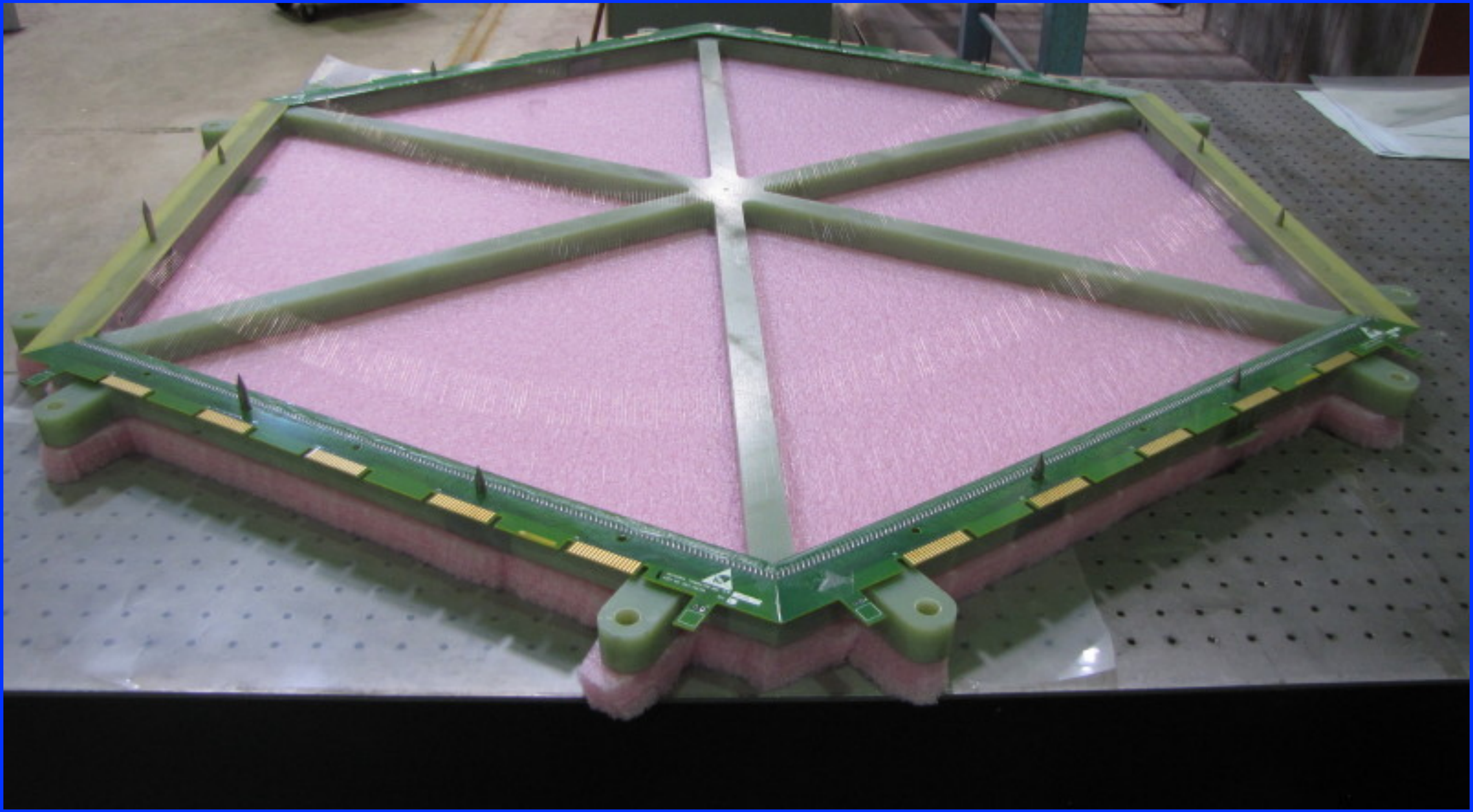
Cryostat arrives at LANL (22 August 2014)

Cryostat arrives at LANL (22 August 2014)

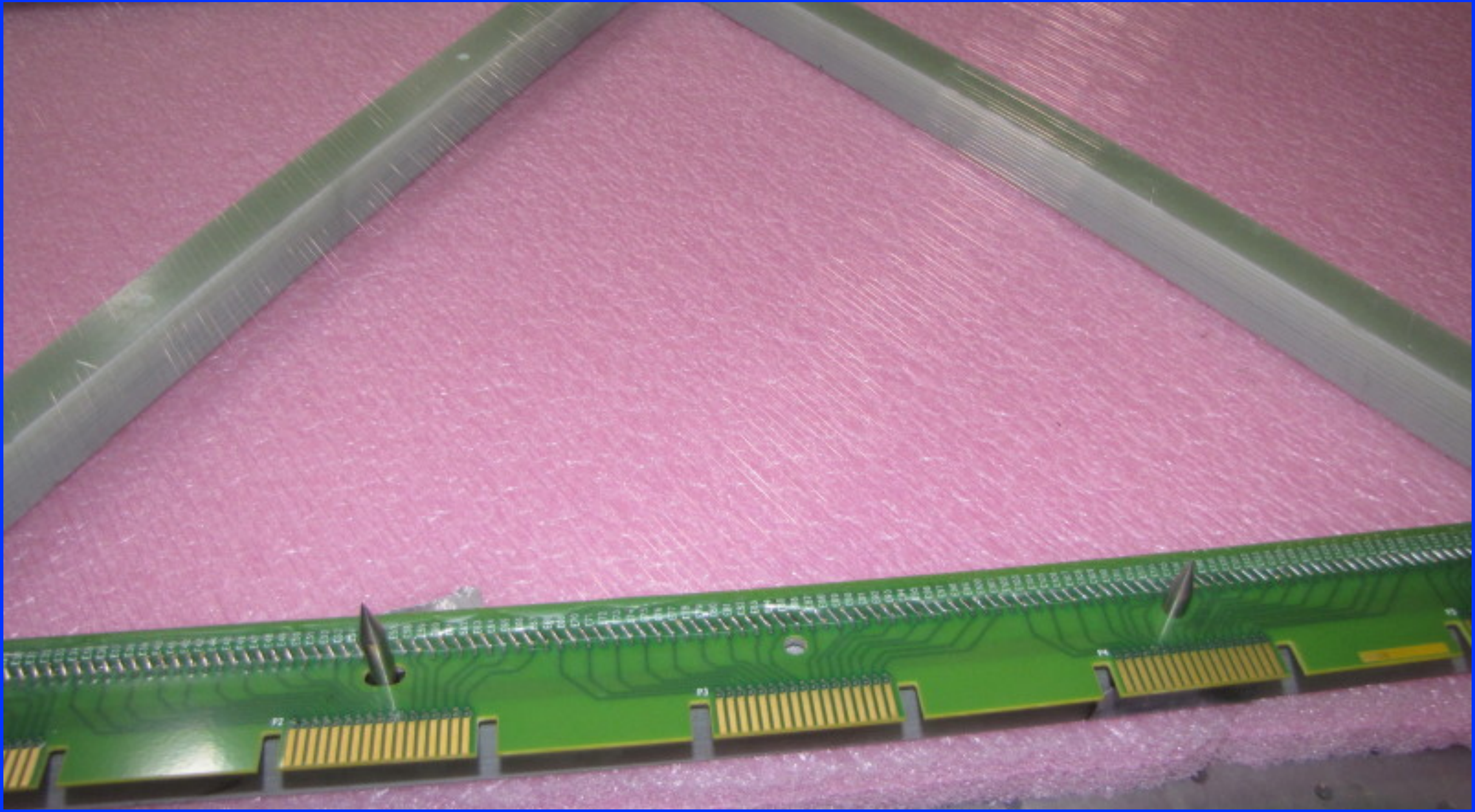
Mini-CAPTAIN field cage



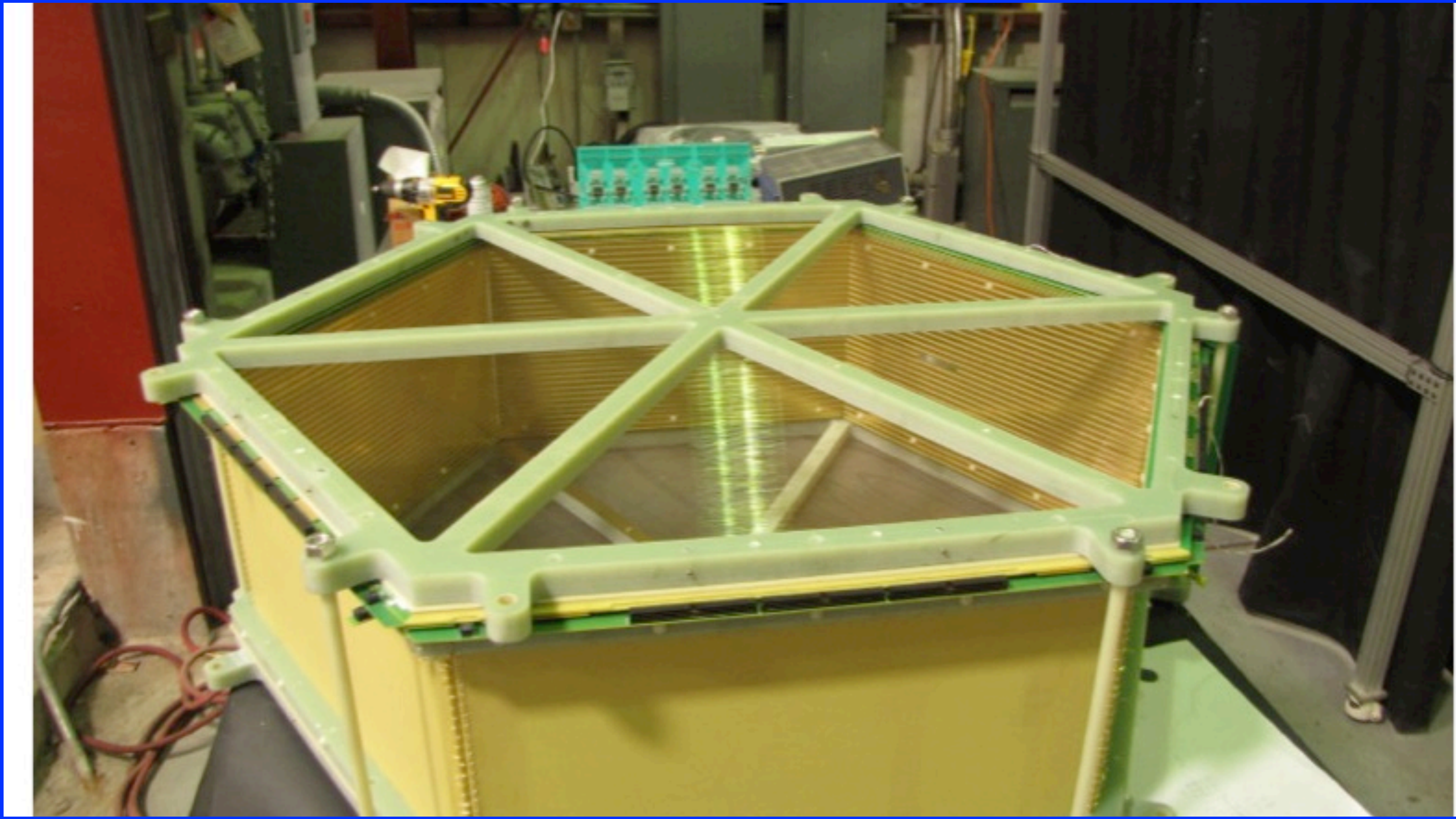
Mini-CAPTAIN wire frame



Wire-frame close-up

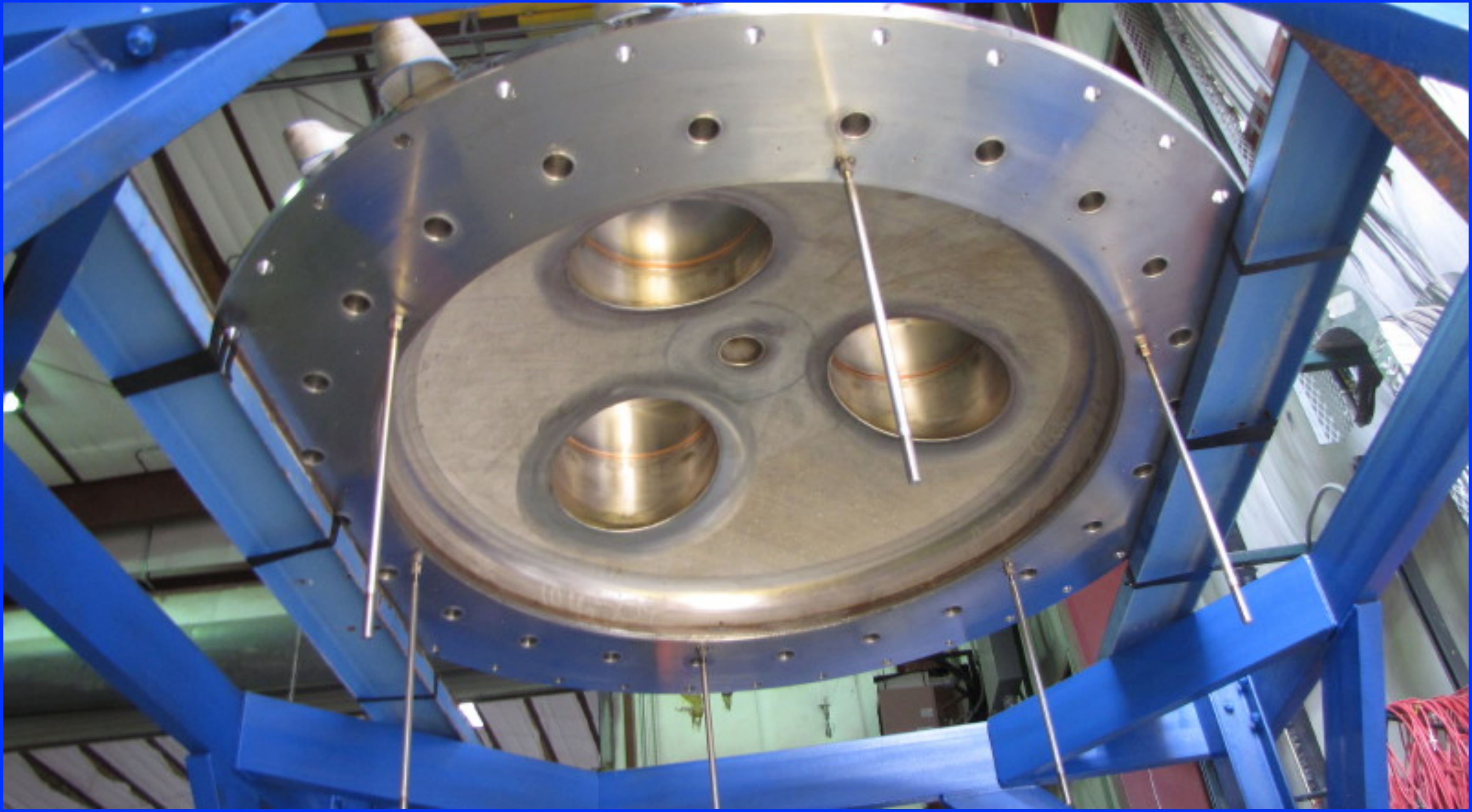


Mini-CAPTAIN TPC assembled

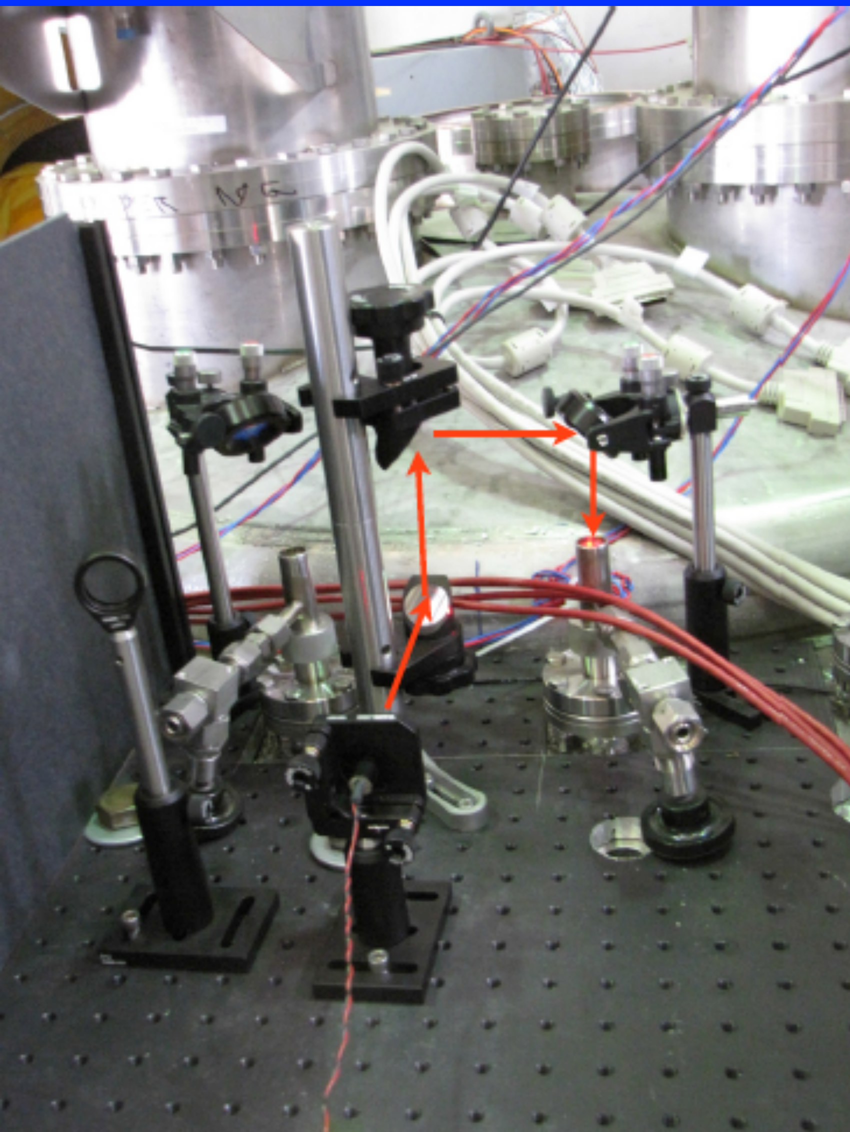


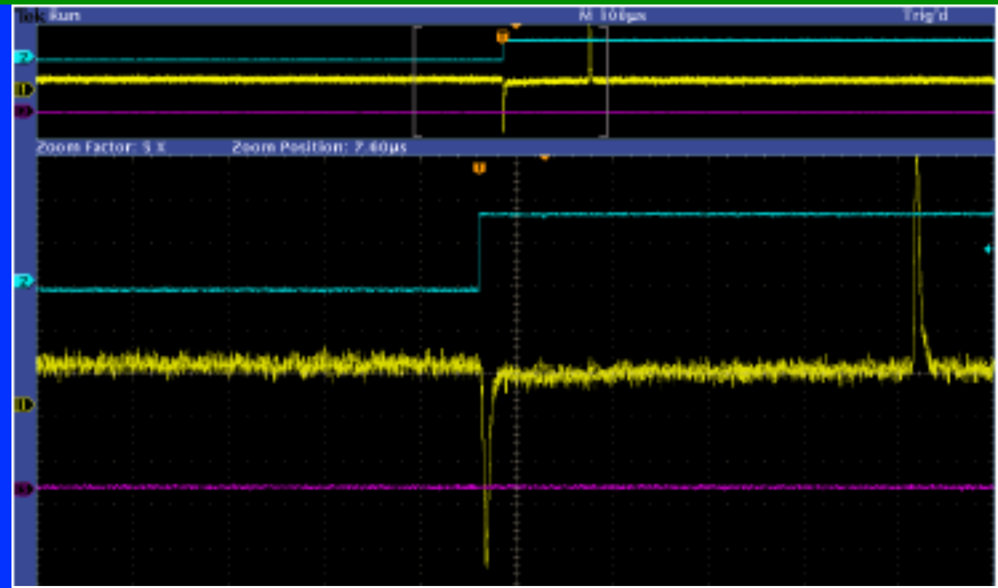
Mini-CAPTAIN cryostat

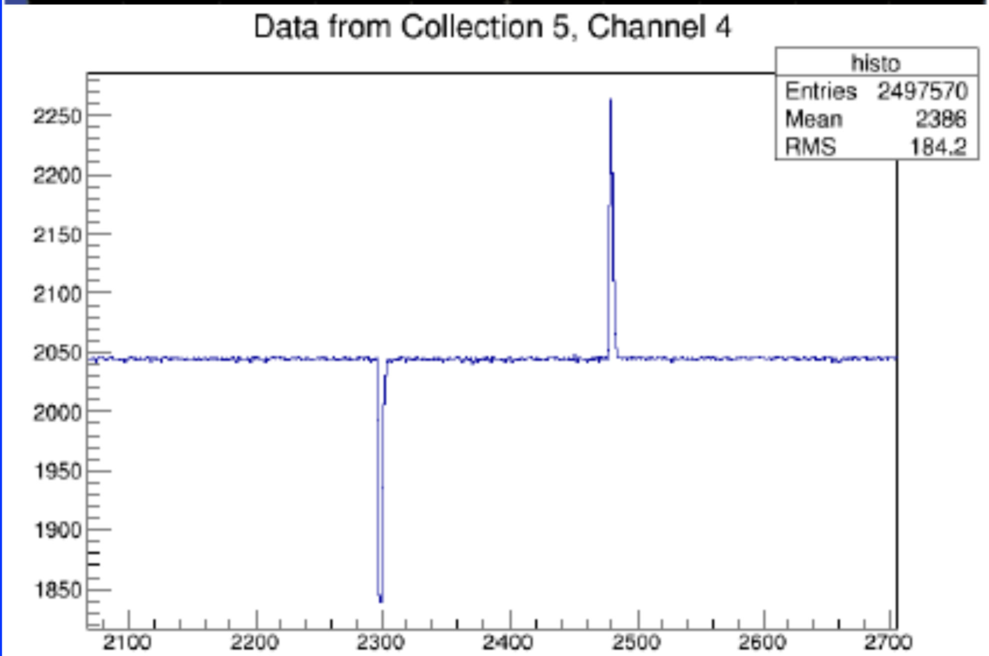
Mini-CAPTAIN lid and support stand



Laser Optics, Electronics tests





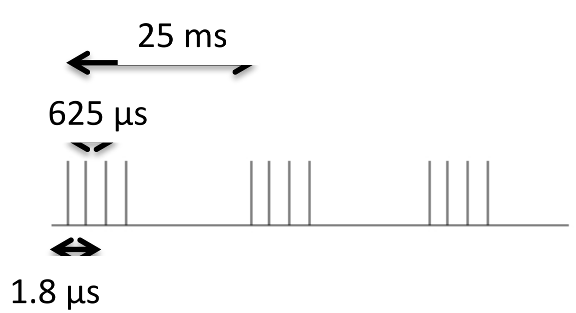


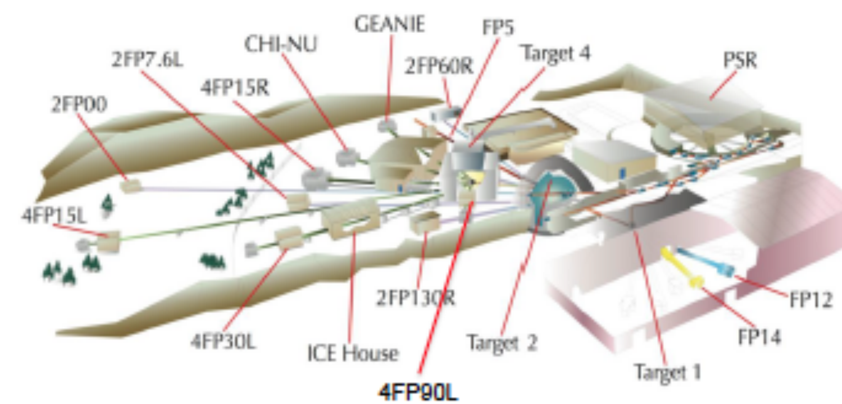
Cryostat at Vendor (April, 2014)

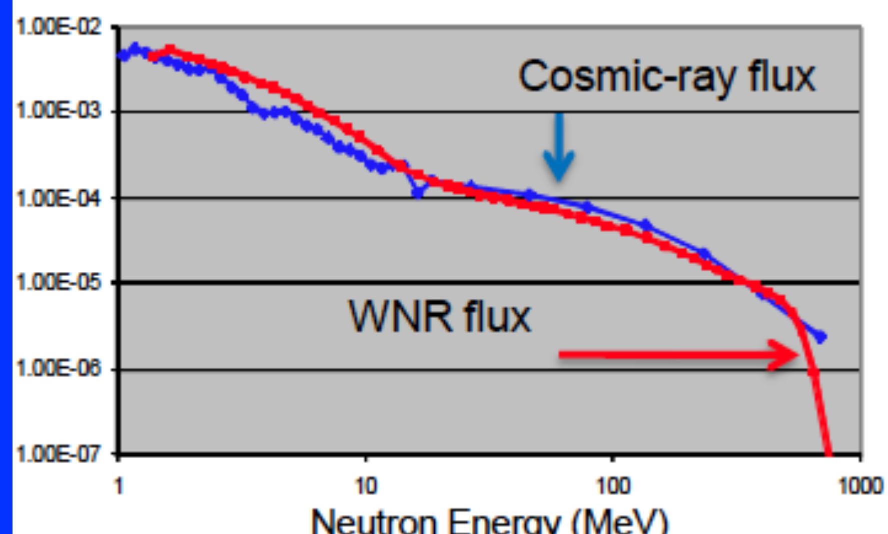
Neutron Beam at LANL

- Los Alamos Neutron Science Center WNR facility provides a high flux neutron beam with a broad energy spectrum similar to the cosmic-ray spectrum at high altitude

- Time structure of the beam
  - sub-nanosecond micro pulses 1.8 microseconds apart within a 625 µs long macro pulse
  - Repetition rate: 40 Hz

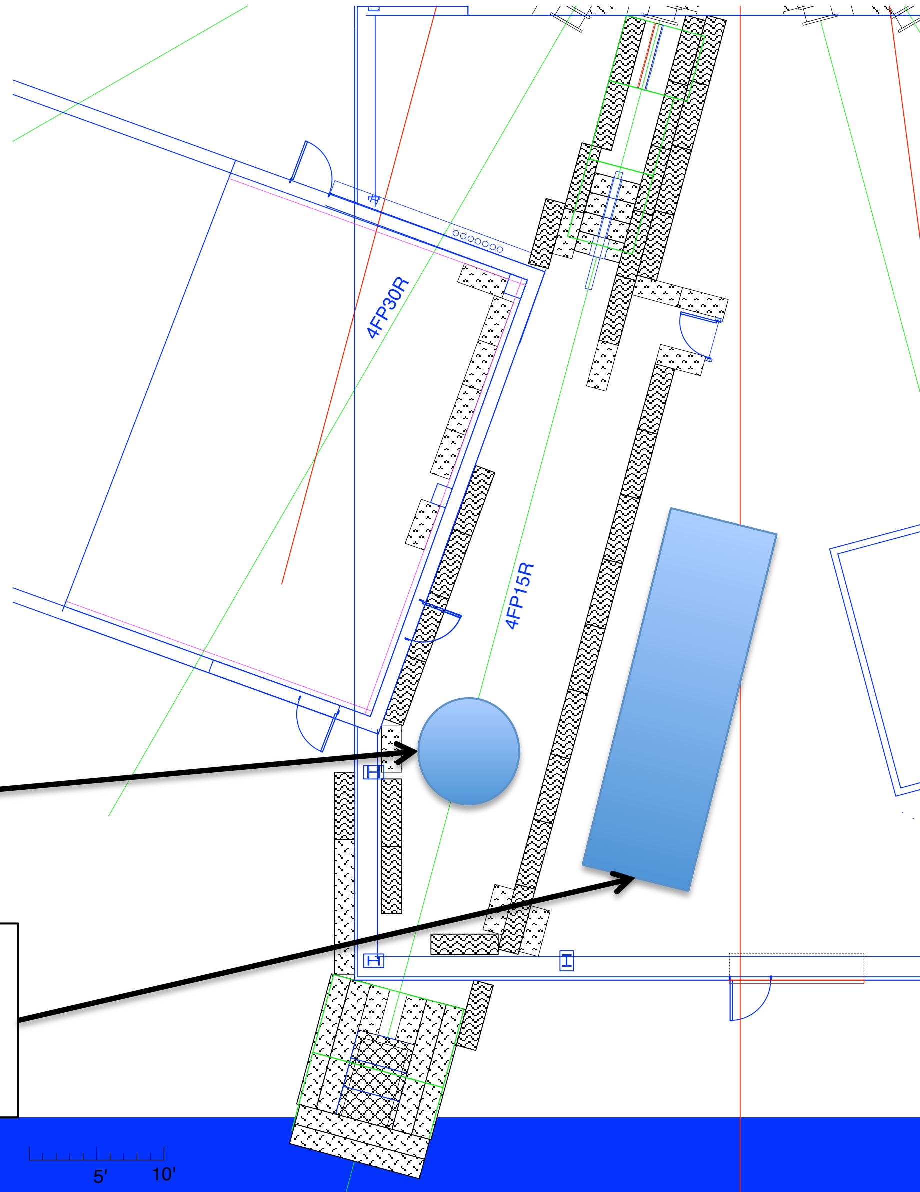






Neutron Beamline

- Anticipate two run conditions:
  - High-intensity (normal) where we expose our detector to a high flux, close the shutter, identify produced spallation events
  - Low-intensity where we get one neutron event per macropulse
- Granted two low-intensity runs last autumn for engineering studies



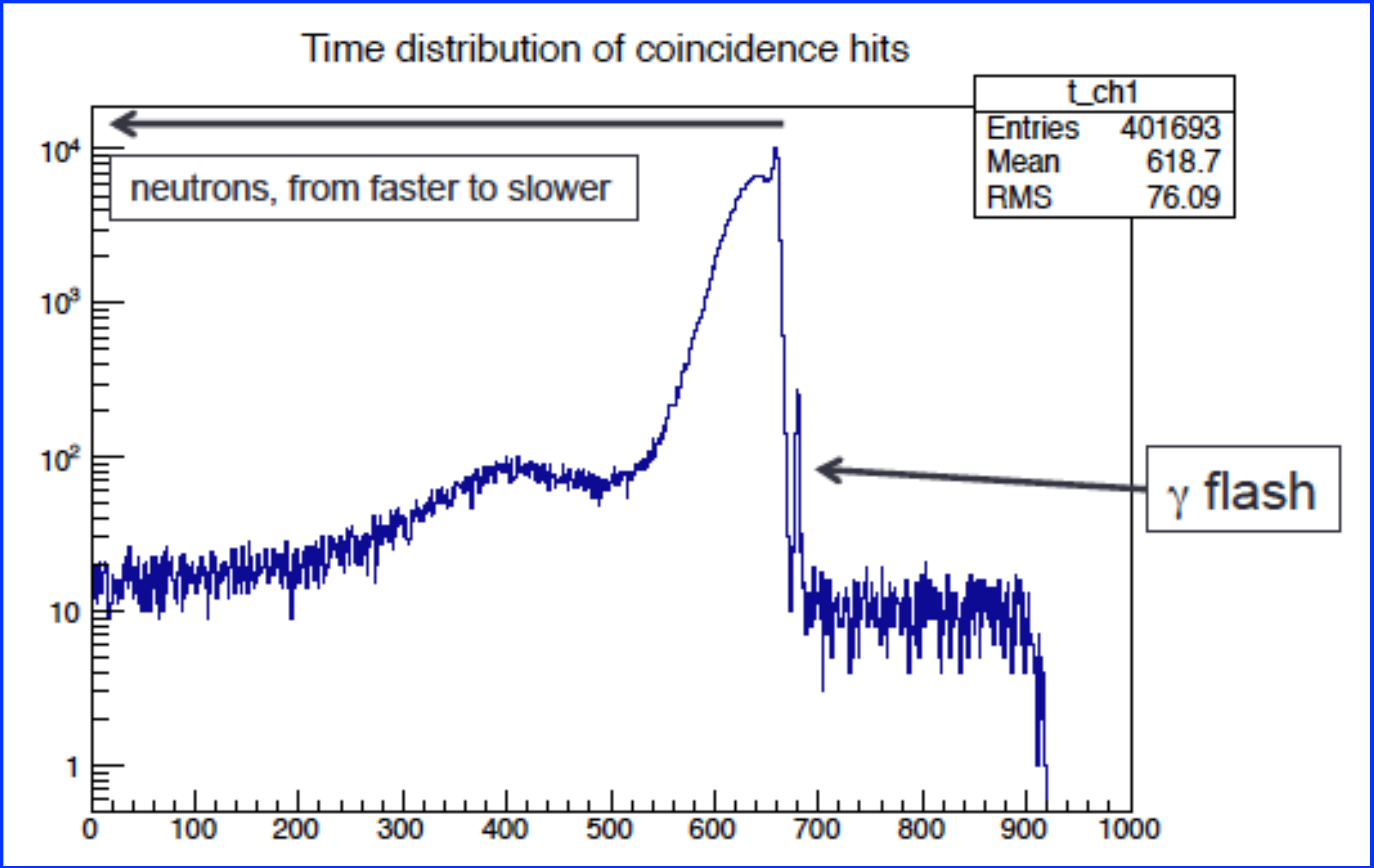
- Electronics and DAQ
- LAr purification system
- LAr cryogenic system

Low-intensity neutron running

48 in long plastic scintillator with 2 PMTs at 25 m from production target

Effort led by Elena Guardincerri

Neutron Data



Neutron rate 0.63 Hz when beam set at 1 micropulse per macropulse